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Studies on Peat in the Coastal Plains of Sumatra and Borneo

Part III: Micromorphological Study of Peat in Coastal Plains of Jambi, South Kalimantan and Brunei

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Abstract

The micromorphology of peats was studied in order to characterize the various stages of decomposition and to describe the overall change of organic matter after deposition. The fallen plant materials consist of leaves, wood blocks, branches and twigs, and they are categorized as litter. Several microfabrics, including fibric, hemic and sapric materials, occur in the course of decomposition. Fibric material is characterized by tissues of recognizable botanical origin, while the hemic and sapric materials are characterized by mainly unrecognizable tissues.

Peats covered by dense forest are mostly characterized by fibric peat in the bottom layer, which is mainly derived from ferns and grasses. In the upper layers these peats are commonly hemic or sapric peats containing many wood blocks derived from the former vegetation. In cultivated areas, thin peat layers are categorized as sapric peats.

The macro- and microorganisms attacking the plant debris control the process of micromorphological change of organic matter and hasten the decomposition of fallen-plant materials. However, the degree of decomposition of peats is closely related to the water contents of organic materials.

Introduction

In recent years, soil scientists and geologists have increasingly sought out peat deposits in tropical regions to study their properties and agricultural potential. However, few studies have been undertaken to characterize the micromorphology of these peats deposited. I have studied the micromorphology of peats by use of the scanning electron microscope (SEM) in order to know their genesis and to investigate the micromorphological changes of organic matter which accompany the decay of fallen-plant materials. Although Polak [1975] has studied tropical peats in detail, she did not record the characteristics of fallen-plant materials on the microscale.

Long before plant materials fall to the ground, they begin a cycle of decay which in many ways is as complex and as fascinating as the decomposition process of plant debris. As the fallen plant

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materials continue to accumulate on the soil surface, they form a pile of organic materials in varying degrees of decomposition, which eventually form peat deposits.

Large areas of peat deposits in Indonesian river basins are situated in Sumatra and Borneo. The accumulation of peats here is clearly due to the waterlogged, and therefore anaerobic, conditions. These peat deposits, which were discussed in the former paper [Supiandi 1988] consist of fibric, hemic and sapric peats. In the field, the materials of fibric peat are mostly characterized by relatively unaltered plant tissue such as wood blocks, grasses, leaves, and roots. Hemic material mostly contains fragments of plant tissue which are partially disintegrated and decomposed. Sapric material is characterized by black organic fragments and brown amorphous materials of unidentifiable botanical origin. This clearly indicates that peats deposited in this basin contain organic matter in different degrees of decomposition.

This paper aims to clarify the micromorphological changes of organic matter during decomposition, that resulted in the different histic materials.

Materials and Methods

To study the micromorphological changes of organic matter since the fallen-plant materials were deposited on the soil surface, samples were collected of fibric peat, hemic and/or sapric peats, leaves, roots, woods, and other plant remains. Fibrist, hemist and saprist materials were classified using the criteria in Table 1. Field criteria in Table 2 were also used in order to determine the

Table 1 Some Taxonomic Criteria for Differentiating Fibrist, Hemist and Saprist Materials (after Soil Survey Staff [1975])

Criteria	Fibrist	Hemist	Saprist
Dominant kind of material in subsurface tier	fibric	hemic	sapric
Decomposition of material	little or none, recognizable botanical origin	intermediate, 2/3 of materials unrecognizable origin	almost complete, botanical origin unrecognizable
Bulk density g/cm^3	less than 0.1	0.07 to 0.18	more than 0.2
Percent water content saturated (by weight oven dry basis)	850 to 3,000 or more	450 to 850	less than 450

Table 2 Field Criteria for Differentiating Fibric, Hemic and Sapric Peats (after Institut Pertanian Bogor Team [1980])

Criteria	Description
Fibric peat	On kneading the soil, less than 1/3 of the soil can exude between fingers
Hemic peat	On kneading the soil, 1/3 to 2/3 of the soil can exude between fingers
Sapric peat	On kneading the soil, more than 2/3 of the soil can exude between fingers

types of peat deposits in each layer.

Peat samples were collected using the subsampling method, for which samples of different histic materials were taken from several peat samples in plastic and/or bamboo pipes. When organic materials became drier during storage, the collected samples were saturated with 1 M $NaHCO_3$ and boiled for observation.

To observe the micromorphology of organic matters, samples were prepared by the method of McKee and Brown [McKee and Brown 1977]. The method consists of (1) sample mounting using a brass specimen stub, for which two-sided adhesive tape and conducting silver paint were used to mount particles onto the specimen stub, and (2) sample coating in order to reduce the specimen charging of nonconducting specimens during observation under the SEM.

Photography and sample observation were done by the routine method using the SEM.

Results and Discussion

Micromorphological Characteristics of Different Histic Materials in Peats

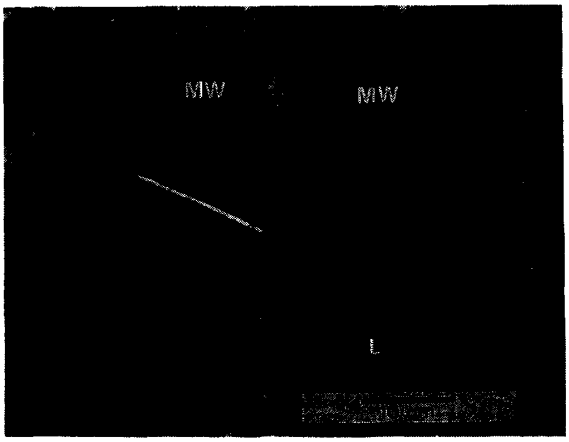
The types of organic materials recognized in peat deposits are fibric, hemic and sapric materials, which are characterized by the different morphology of decayed plant tissues. The fallen plant materials deposited on the soil surface can be categorized as litter, and are usually characterized by layers of organic matter derived from plant debris. In places, peaty soils were also found, and they are characterized by the admixture of peat and mineral materials.

The peaty nature of these deposits was substantiated by the rapid change in color of soil matrix (in the wet condition) during observation in the field from dark reddish brown (5YR 3/2-3/3) to black (10YR 1.7/1-2/1). This is probably because of the polymerization of polyphenols on contact with air.

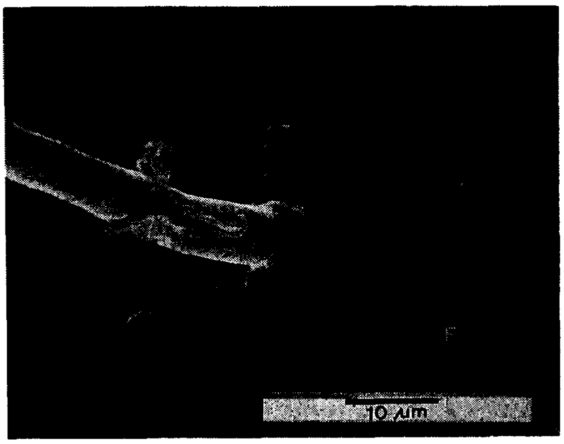
In the following discussion, I attempt to differentiate the type of these peats based on the results of micromorphological observation. The macromorphological characteristics of organic materials were observed in the field.

Litter

The fallen-plant materials deposited on the soil surface are characterized by layers of forest litter. In these materials, consisting primarily of leaf litter, it is possible to recognize twigs, wood blocks and branches associated with organic materials. For instance, Plate 1-1 shows the macromorphology of fallen-plant materials taken from peat deposits in the coastal plain of Jambi. This plate indicates that many plant remains are clearly identifiable as to their botanical origin. On the microscale, Plate 1-2 shows the micromorphology of fallen leaf material, for which the leaf hair (H) is clearly visible. This means that the fallen leaf material was not yet completely decomposed. However, the leaf epidermis had started to shatter (see Plate 1-2), and this allowed the imperfect fungus, which is shown by the conidium (Plate 1-2 marked by F), to attack the fallen

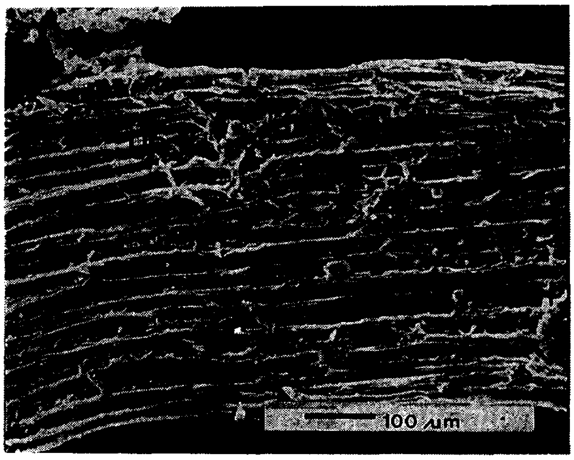


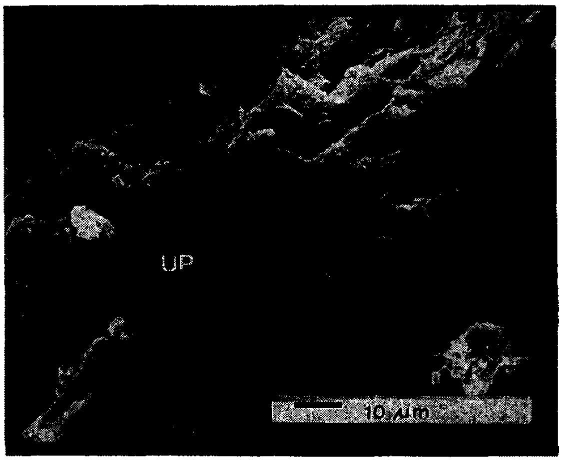
1-1 The Photograph of Litter Consisting of Moldy Wood (MW) and Leaf (L)



1-2 The Scanning Electron Micrograph of Leaf Surface Taken from Leaf Litter; H, Leaf Hair; F, Conidia of Imperfect Fungus

Plate 1 Litter Taken from Soil Surface





UP, Unaltered Plant Tissue

Plate 2 The Scanning Electron Micrograph of Undecomposed Remains of *Phragmites* sp.

Plate 3 The Scanning Electron Micrograph of Undecomposed Remains of Plant Root

leaf material. This shattering plays an important role at the beginning of leaf litter decomposition.

Fibric Materials

Fibric materials are mostly deposited in the bottom layers. They contain large amounts of fibers (several fragments of plant tissue) that are well preserved and mostly identifiable botanical origin. Many plant remains are little decomposed, so their origins are clearly recognizable: wood blocks, roots and grasses. For instance, Plates 2 and 3 show the remains of *Phragmites* sp. and plant root, respectively. These materials are still characterized by a fibrous matrix of relatively unaltered plant tissues.

The results of macro- and micromorphological observation of organic materials of Profiles B-15 from Jambi (at the

Table 3 Water Content and Bulk Density of the Top 50 cm of Samples from the Coastal Plains of Jambi and South Kalimantan

Jambi					South Kalimantan				
Profile No.	Depth (cm)	Bulk Density (g/cm³)	Water Content* (%)	DD**	Profile No.	Depth (cm)	Bulk Density (g/cm³)	Water Content* (%)	DD**
B-12	10-15	0.16	335	H	BM-11	5-10	0.26	272	S
	15-20	0.15	480	H		15-20	0.19	390	H
	35-40	0.13	443	H		25-30	0.15	537	H
						35-40	0.21	470	H
						45-50	0.13	718	H
B-15	0-5	0.19	289	S	BM-24	5-10	0.31	354	S
	5-10	0.14	464	H		15-20	0.25	443	S/H
	25-30	0.12	615	H		25-30	0.25	386	S/H
						35-40	0.23	464	H
RTP-7	5-10	0.14	228	H	BM-33	5-10	0.35	293	S
	10-20	0.16	344	H		15-20	0.36	302	S
	25-30	0.13	545	H		25-30	0.36	292	S
	40-45	0.11	684	H		35-40	0.34	323	S
	50-55	0.11	725	H		45-50	0.34	320	S
RTP-21	10-15	0.19	239	S	BM-39	5-10	0.21	457	S/H
	15-20	0.17	225	H		15-20	0.29	385	S
	20-25	0.15	267	H		25-30	0.42	280	S
	30-35	0.14	245	H		45-50	0.42	289	S
T-21	5-10	0.22	293	S	BM-41	5-10	0.33	327	S
	15-20	0.15	508	H		15-20	0.35	340	S
						25-30	0.32	353	S
						45-50	0.28	422	S

* Oven-dry basis (105°C)
** Degree of decomposition
S, sapric peat; H, hemic peat

depth of 100 to 540 cm), BM-41 from South Kalimantan (at the depth of 50 to 195 cm), and BRNI 86-28 from Brunei (at the depth of 50 to 330 cm) indicate that all these materials can be categorized as fibric peat.

Hemic and Sapric Peats

The organic materials classified as hemic or sapric peats were mostly found above the fibric peat layer. In the field, these materials are commonly characterized by the fact that their botanical origin is not recognizable. Their bulk density varies from 0.11 to 0.36 g/cm³ (Table 3). The bulk density of hemic peat is usually between 0.1 to 0.2 g/cm³, while that of sapric peat tends to be more than 0.2 g/cm³.

The hemic materials can be catego-

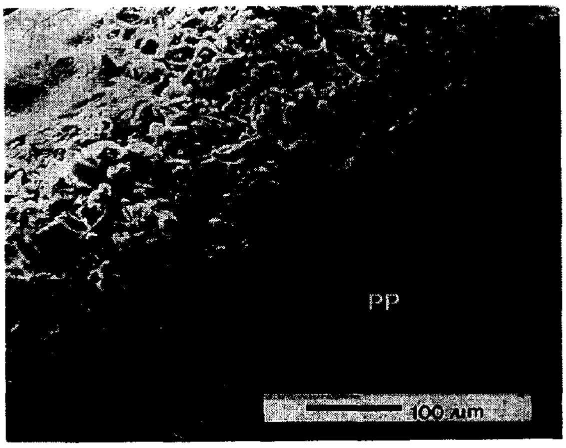
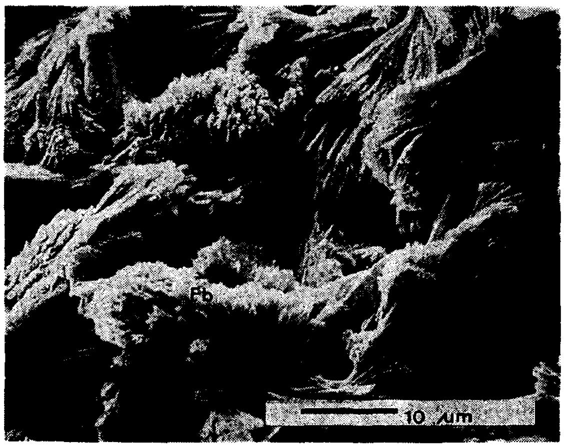


Plate 4 The Scanning Electron Micrograph of Decomposed Organic Matter of Hemic Peat after Boiling with 1 *M* $NaHCO_3$; PP, Packed Porous Material

rized as moderately to well decomposed peats which are dark brown in color. The microfabric of these materials is characteristically loosely packed and porous. For instance, Plate 4 shows a fragment of hemic peat after boiling with 1 M $NaHCO_3$. This plate illustrates that the original plant materials were decomposed, giving rise to a coarse porosity.

Sapric peat is composed primarily of brown amorphous materials whose botanical origin is not identifiable. In the cultivated coastal plains of Jambi and South Kalimantan, the sapric materials are characterized by black organic fragments, Whereas the sapric peat under forest commonly contains brown fragments throughout the matrix as well as a few black (10YR 1.7/1) fragments. When the samples became drier during storage, they formed pelletized granules. Plates 5–1 and 5–2 show pelletized

5–1 The Scanning Electron Micrograph of Decomposed Organic Matter of Sapric Peat after Boiling with 1 M $NaHCO_3$



5–2 The Scanning Electron Micrograph of Fibers (Fb) of Pelletized Granule of Sapric Peat

Plate 5

Plate 6 The Scanning Electron Micrograph of Decomposed Organic Matter of Air-dried Hemic Peat

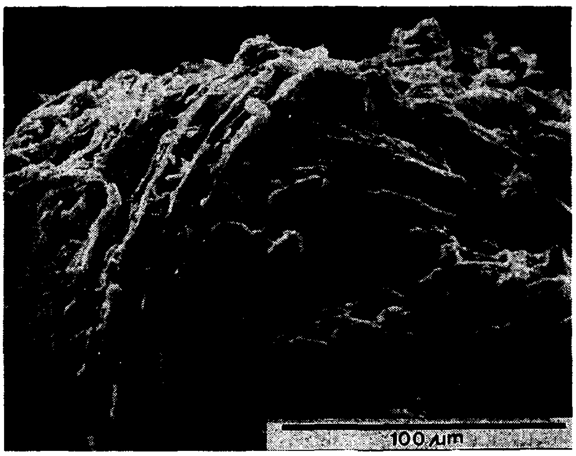


Plate 7 The Scanning Electron Micrograph of Decomposed Organic Matter of Air-dried Sapric Peat

granules of sapric peat after boiling with 1 M $NaHCO_3$. These plates indicate that the organic materials are almost completely decomposed. However, a microfibrillar component of pelletized granules is still recognizable under the SEM, and probably consists of lignin microfibrils as well as cellulose and/or hemicellulose microfibrils.

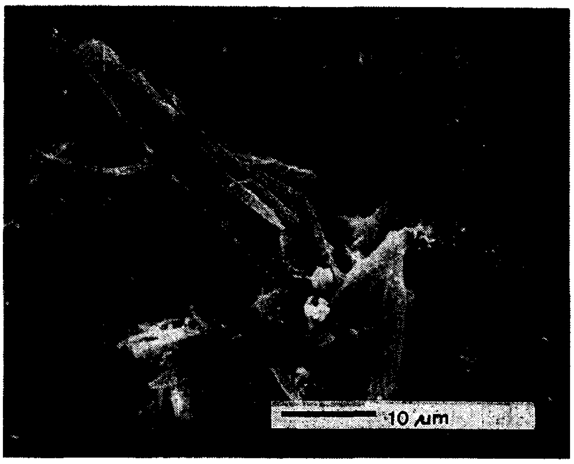
Plates 6 and 7 show fragments of air-dried hemic peat and air-dried sapric peat, respectively. Plate 6 indicates the absence of packing pores of hemic peat. Likewise, Plate 7 shows that the microfibers of pelletized granules of air-dried sapric peat are not obvious. This is because the fragments of hemic and sapric peats have probably been associated with humic substances as well as with mineral materials. The presence of humic substances in the peat is believed to influence the micromorphology of the microfibers of pelletized granules. Leaching the peat samples with 1 M $NaHCO_3$, which removes the humic substances, might clearly reveal the microfibrillar component of pelletized granules (see Plates 4 and 5).

Peaty Soils

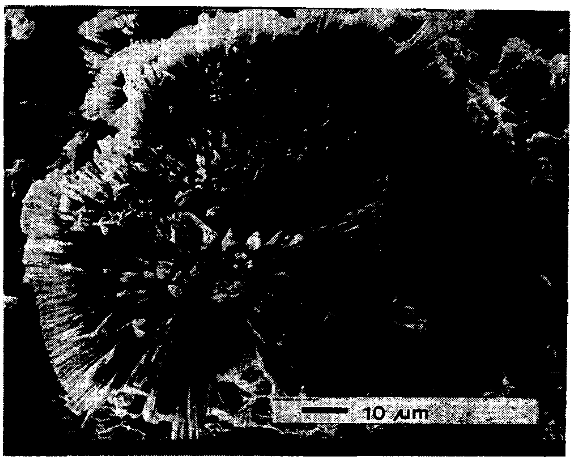
Peat deposition in the coastal plains is sometimes accompanied by deposition of mineral materials, resulting in the formation of peaty soils. This type is often found in brackish to marine deposit zones which are influenced by daily tidal fluctuations of rivers.

In the mineral riverine deposit zone, the influx of mineral materials is caused by annual fluctuation of rivers inland. These mineral materials are carried by the flood-waters of the river. When the water recedes, the mineral materials are deposited on the peat deposits. As the vegetation continues to grow, this mineral material leyer is again covered by organic matter to form alternate layers of peat and mineral soils.

In the peaty soil samples, I found gypsum crystals associated with the pelletized granules (Plate 8). The formation of these gypsum crystals is due to the presence of calcium in peat and mineral



A, Gypsum Crystals



B, Gypsum Needles

Plate 8 The Scanning Electron Micrograph of Gypsum Associated with Decomposed Organic Matter

Table 4 Total Contents of SiO_2 and CaO in Soils from the Coastal Plain of Jambi

Profile	Depth (cm)	Stratigraphic Type*	SiO_2 (%)	CaO (%)
B- 8	0-138	P	52.65	18.00
	138-162	Tt	55.33	0.07
	162-347	P	51.15	1.88
	347-418	Tt	54.54	0.77
	418-532	Te	62.46	1.25
B-10	0- 20	P	61.43	10.37
	20-146	P	53.40	2.35
	146-186	Tt	61.24	0.002
	186-249	P	48.78	0.24
	249-262	Tt	53.07	0.28
	262-304	P	47.33	0.53
	304-460	P	49.84	0.73
	460-502	Te	79.37	0.07
T-24	80-150	P	46.34	1.94
	150-227	M	70.13	0.34
	227-263	M	68.19	0.13
L- 3	0- 13	Tt	67.79	3.65
	13- 34	Tt	67.16	0.28
	34- 63	M	68.87	0.32
	379-400	Ti	64.75	0.88
	500-600	Ti	61.13	0.78

Note: On ignited basis

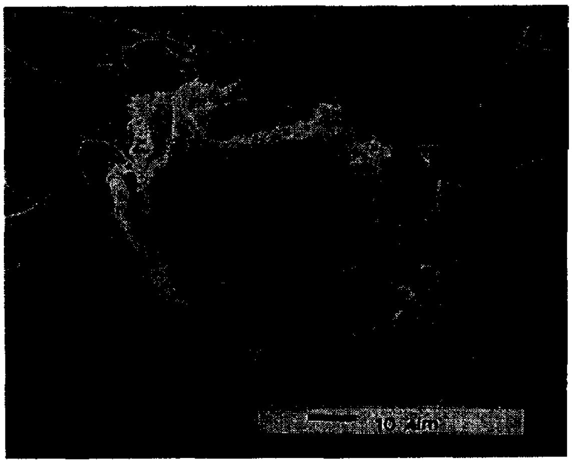
* See the Study of Physiography and Geomorphology of the Coastal Plains presented in Part I [Supiandi 1988].

M, Mangrove deposits; P, Peat; Te, Pleistocene terrace; Ti, Tidal flat; Tt, Fluviatile sediment.

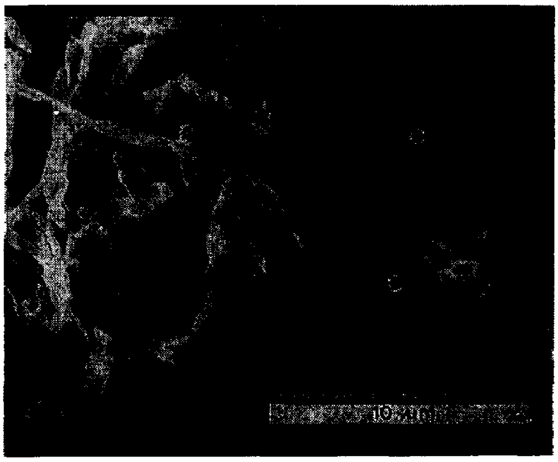
soils (see Table 4). In the soil solution, this calcium would react with sulfate derived from the decomposition of organic matter, to form gypsum. According to Stevenson [1982] the decomposition of organic matter yields CO_2, NH_4^+, NO_3^-, PO_4^{-3} and SO_4^{-2}. When the soil became drier, the gypsum would have been precipitated in association with the pelletized granules. Differentiation of gypsum crystals and the microfibrils of pelletized granules of peats is sometimes difficult, because both have similar micromorphology. To distinguish them, the samples were saturated with 1 *M* $NaHCO_3$ and boiled in order to remove the gypsum crystals, for which the results can be seen in Plates 4 and 5.

Micromorphological Changes of Organic Matter

The decomposition of fallen plant materials on the soil surface was hastened by microorganisms such as imperfect fungi. For instance, Plates 9-1 and 9-2

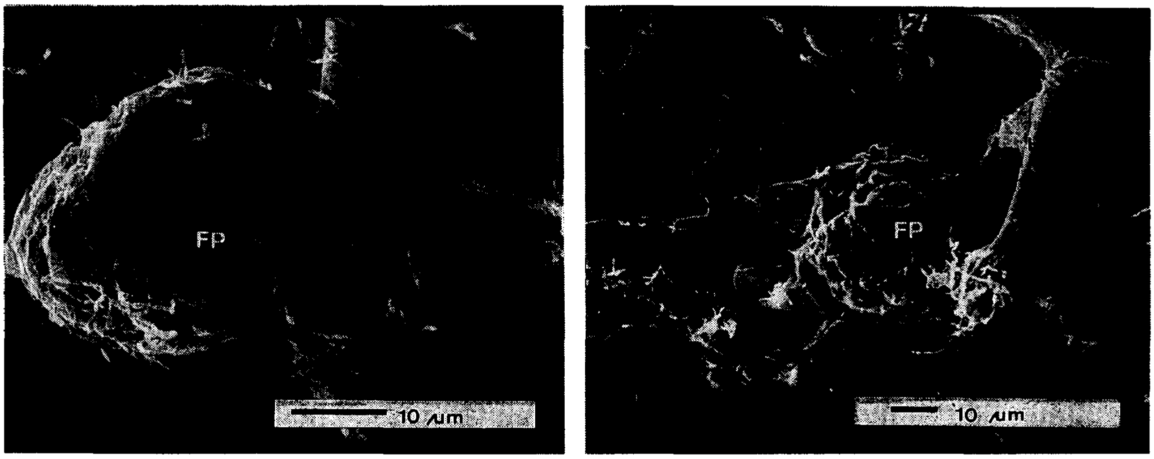


9-1 Colony of Imperfect Fungi Taken from the Leaf Litter



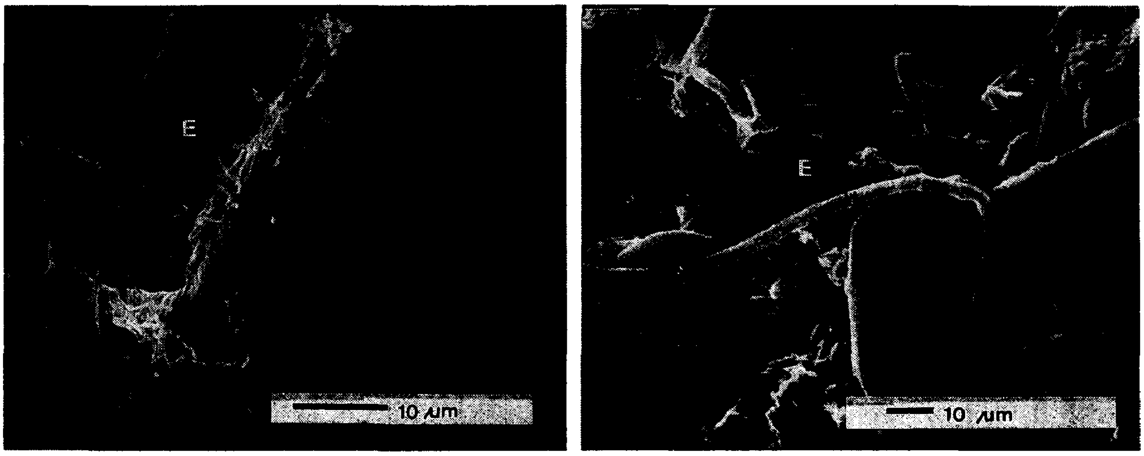
9-2 Conidia of Imperfect Fungi Attacking the Leaf; Some Conidia Entering to the Cells (C)

Plate 9 The Scanning Electron Micrograph of Imperfect Fungi Taken from the Leaf Litter



FP, Fecal Pellets; H, Leaf Hair

Plate 10 The Scanning Electron Micrograph of Fecal Pellets Taken from Leaf Litter



11-1 Conidia of Imperfect Fungi Attacking the Epidermis (E) and Leaf Hair (H)

11-2 Epidermis Decay (E) and Leaf Hair (H)

Plate 11 The Scanning Electron Micrograph of Imperfect Fungi Attacking the Leaf Debris

show the conidia of imperfect fungi attacking fallen leaf materials. The other important decomposers are soil fauna. This is substantiated by the presence of fecal pellets, which were small and egg-shaped (see Plate 10). From observations under the SEM, the fecal pellets are always attached to a leaf hair.

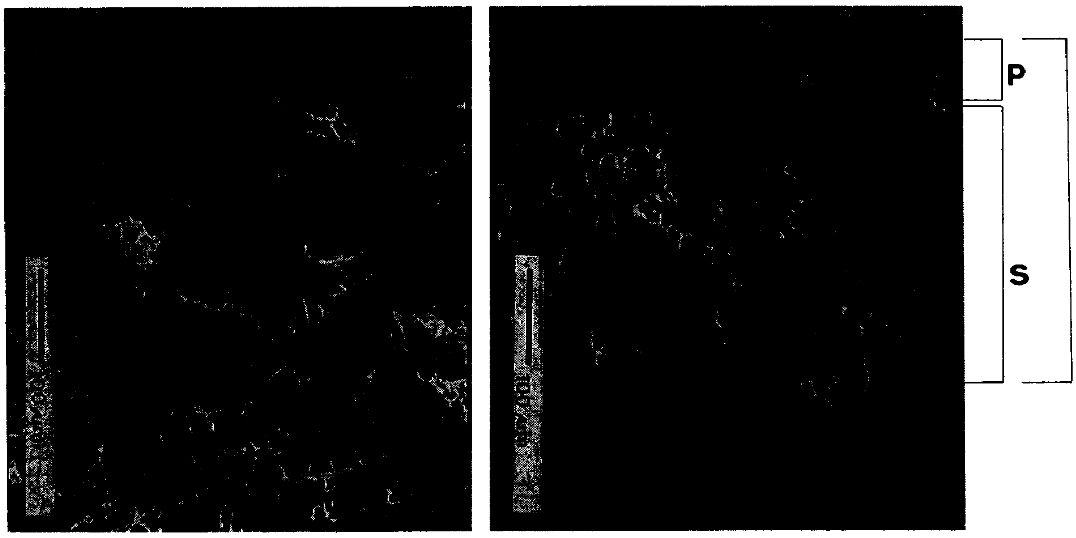
The decomposition of fallen plant materials causes a change in the form of the litter-fall. The micromorphological changes of fallen plant materials in the process of decomposition are described below.

Leaf Material

When a leaf falls on the wet soil surface, the leaf skin, called the epidermis, namely, the outermost layer of leaf cells, is first gradually shattered. For example, Plate 11-1 shows the outermost layer of leaf cells starting to be shattered. This eventually produces leaf debris. The conidia of imperfect fungi then attack the leaf debris to accelerate the decomposition, causing the epidermis and leaf hair to be completely shattered (see Plate 11-2). Next, the mesophyll, namely, the soft tissues contained between epidermal layers, is gradually shattered to produce the broken cellular structure of leaf which is clearly visible under the SSEM (Plate 12-1). Likewise, from the transverse section of leaf, the palisade and spongy layers of mesophyll are still visible, as shown in Plate 12-2. This means that leaf debris piled on the soil surface, in which the broken cellular structure of leaves is still visible, is probably characteristic of the first stage of decomposition.

Wood Material

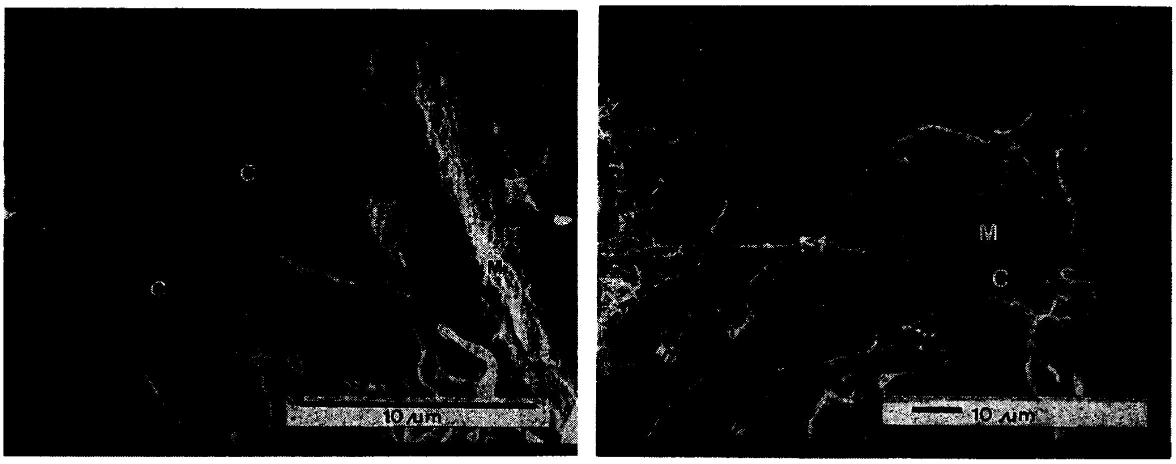
The main characteristic of the coastal



12-1 Broken Cells of Leaf Taken from Leaf Surface

12-2 Cross-section of Broken Cells of Leaf; P, Palisade Layer; S, Spongy Layer

Plate 12 The Scanning Electron Micrograph of Broken Cells Taken from Leaf Litter



13-1 The Scanning Electron Micrograph of Conidia of Imperfect Fungi Attacking Moldy Wood; Some Conidia Entering to the Cells (C)

13-2 The Scanning Electron Micrograph of Conidia of Imperfect Fungi Attacking Moldy Wood; M, Moldy Wood; C, Conidium

Plate 13

plains in Jambi and Brunei is that they are covered by dense forest, which is dominated by tree species. In South Kalimantan, the forest has disappeared due to human activities. The trees growing on the swampy land mostly stand on mud clay and/or peat, so they often fall because their roots have no strong anchoring.

When wood debris starts to decay, the bark is first decomposed. Then the wood shatters to produce so-called moldy wood, which is presented in Plate 1-1. Imperfect fungi then attack the moldy wood (see Plates 13-1 and 13-2) to accelerate the process of decomposition, causing the wood debris to decay further, so that the wood fibers are not easily recognizable (Plate 14).

However, some of trees in the coastal plain have a high content of lignin [Polak 1975]. I believe that the silica content of the wood material is also high, because the total silica content of the peat deposits (Table 4) is usually more than 50 percent on an ignited basis. The highest content of silica in these deposits is believed to be accumulated in the wood material. This causes the wood debris to be resistant to decay, and this is why it was not completely decomposed.

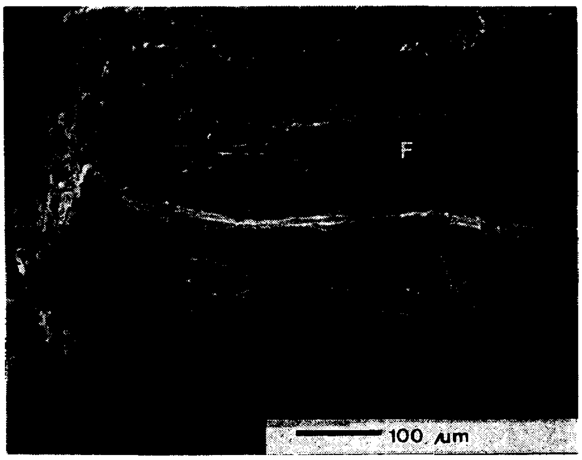


Plate 14 The Scanning Electron Micrograph of Fibers of Moldy Wood; F, Fibers

Plant Root

In general, three kinds of root systems were found, namely, stilt roots, plank buttresses, and spreading roots. Stilt roots are characteristic of mangrove vegetation, and plank buttresses are characteristic of big trees growing behind mangrove vegetation. The plank buttresses have secondary and tertiary vertical and/or lateral roots which penetrate shallowly into peat. According to Furukawa [1987], the rooting system of *alan* (*Shorea albida*) in the coastal plain of Brunei has a four-storied structure, namely, (1) huge buttresses, of which the height is about 1.0 to 1.5 m from the soil surface, (2) roots of the scaffolding structure, of which the root diameter is about 20 cm, (3) denser root woods branching out from the above, of which the diameter of root wood is about 5 cm or less, (4) long, single roots penetrating deep into peat, which appear to come from the scaffolding root layer, and of which the diameter of root wood is about 3 cm or less. The spreading roots are the rooting system of the vegetation forming the undergrowth, and these roots produce the finer roots with many root hairs.

The roots associated with the decomposed materials are mostly derived from denser root woods with diameters of about 3 cm or less, while others are de-

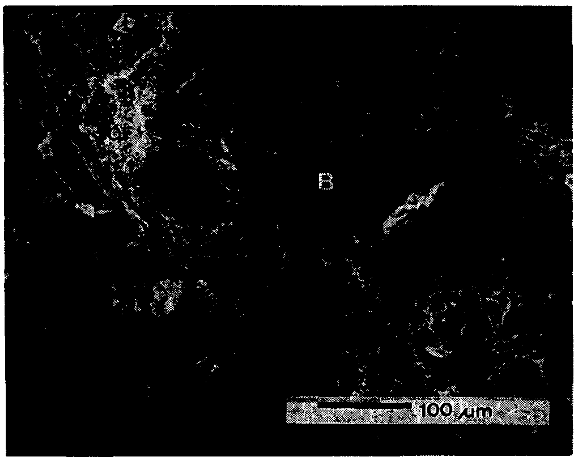


Plate 15 The Scanning Electron Micrograph of Root Remains with Colony of Imperfect Fungi; B, Root Skin; CF, Colony of Imperfect Fungi

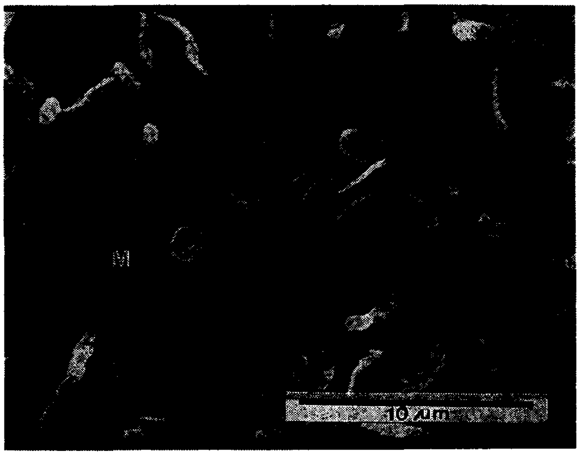


Plate 16 The Scanning Electron Micrograph of Conidia of Imperfect Fungi Attacking Moldy Finer Root; M, Surface of Moldy Root

rived from the finer and spreading roots. In this study, finer and denser roots were observed under the SEM. When the finer and denser roots break from root system, they become associated with other decomposed materials. Plate 15 shows root remains that are almost completely decomposed. Imperfect fungi are attacking this root fragment, hastening the decomposition of the moldy roots.

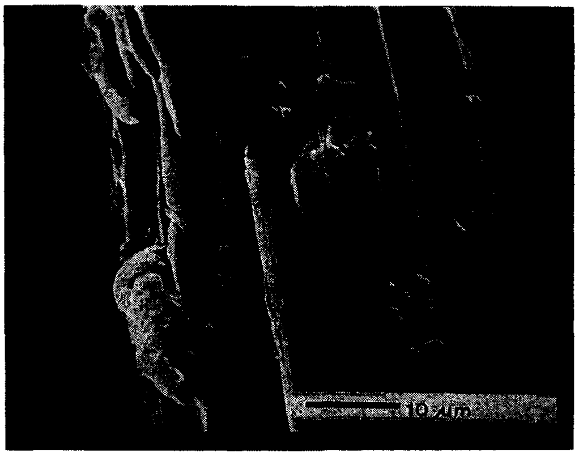


Plate 17 The Scanning Electron Micrograph of Decomposed Root Hair

Plates 16 and 17 show a moldy finer root and a decomposed root hair, respectively. Plate 17 clearly shows that the skin of the root hair was first shattered in the decomposition of the root hair.

Conclusion

The results of this investigation indicate that the micromorphological changes of organic matter are controlled by: (1) the oxidation process, (2) the activities of macro- and microorganisms, (3) the nature of the fallen plant materials, and (4) human activities. It thus concluded that peats deposited under waterlogged conditions are mainly characterized by the materials of recognizable botanical origin, like leaves, roots, wood blocks, and grasses. These peats are mostly found in the bottom layers. In contrast, the upper layers are not influenced by stagnant water, and the organic matter consequently undergoes decomposition. The thin peats in cultivated areas are characterized by unidentified organic materials.

The macro- and/or microorganisms attacking the plant debris are not the main factor in peat formation, but they do accelerate the process of decomposition. The degree of decomposition of peats is closely related to the water contents of organic materials.

Not all the wood debris is completely decomposed; rather, many wood blocks remain mixed with the decomposed materials to form the so-called woody peat. The thin peats in the cultivated areas are categorized as in the sapric peat stage of decomposition.

Acknowledgements

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